ECOSYSTEM PROFILE ANALYSIS AND PERFORMANCE CURVES AS TOOLS FOR ASSESSING ENVIRONMENTAL IMPACT

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An overall ecological paradigm that provides a guideline for the practice of environmental assessment is, in our opinion, expressed quite adequately by the familiar adage that the forest is indeed more than a collection of trees. In more formal terms this paradigm can be stated something as follows: As living and non-living components are combined to produce successively larger and more complex levels of organization there is vertical integration resulting in new or emergent properties not discernible or assessable on the basis of identification and study of sub-components alone. In our opinion, most impact statements are inadequate because they focus on the wrong level -- often, for example, on the species or factor level when the questions and decisions involve the ecosystem level. Accordingly, environmental impact assessment should be evolving rapidly from component analysis (wherein factors and organisms are scaled and weighted as if they were independent entities with no interaction function) to more holistic approaches (whereas interactive and integrative properties are also included).

Although systems ecology, as a manifestation of the holistic approach, has become a vigorous theoretical science, there has yet been little spin-off into the applied field. In fact, many practitioners in the impact business have expressed disappointment in, or outright skepticism about, the value of large-scale ecosystem models such as those generated by the U.S. IBP (International Biological Program) and other team projects that focus on particular environments. While the time-lag between theory and practice tends to be shortened when the need or demand is intense, it still takes time to bridge the gap. In our opinion, large-scaled computerized mathematical models have a way to go before they will have much utility in the day-to-day need for decisions on how, when, where (or if) natural systems are to be modified or impacted by man-made systems. Despair not, however, because there are less sophisticated holistic approaches and models that can be applied in the meantime to augment the present state of the art which, as already noted, is becoming daily more inadequate and frustrating to both the preparators and the users of EISs.

Based on another well-known adage that a picture is worth a thousand words, we suggest that pictorial and graphic models provide the logical procedure intermediary between the piecemeal and the holistic assessments. We propose to discuss and illustrate several forms for such graphic models. For one thing, use of graphic models could greatly reduce the size of EISs which now often end up as thick tomes that nobody ever reads. Theoretically, an Impact Statement need not be any longer than the average journal paper, with perhaps an Appendix of raw data and an outline of the computer program, if one was employed, in case future reassessments are needed.

First, however, let us reaffirm some of the advantages of a holistic approach. Table 1 contrasts selected component measurements that might be appropriate for a body of water with analogous but more functional measurements which more nearly assess system properties. The items in the left-hand colum represent the kind of static or "standing state" physical and biological "factors" which often provide the primary basis for an Impact Statement. Yet, by themselves, these items reveal very little useful information about the body of water. In contrast, the more holistic properties in the right-hand column not only serve as indices to important metabolic functions, but also provide considerable information on interactive and integrative functions. For example, measurement of diurnal oxygen metabolism gives a picture of the net interaction of photosynthesis (P) with respiration (R). The ratio between P and R, of course, indicates whether the aquatic community is autotrophic, heterotrophic, or roughly steady-state, information that would be very important in judging the potential impact of a procedure that might increase the input of organic matter or change the temperature of the water. Likewise, indices of species diversity reveal how species and individuals interact and, in some cases at least, give a clue as to the developmental status of the community, thus providing more information than would a mere list of species. And so on down the list in Table 1.

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Table 1. Comparison of the Component and Ecosystem Approaches to the Assessment of a Body of Water.

Factor-level Measurements (Standing States)	Ecosystem-level Measurements (Dynamic States)
Dissolved Oxygen (D.O.)	Diurnal Oxygen Metabolism
Dissolved Phosphate	Phosphate Turnover Rate
Phytoplankton Biomass	Chlorophyll Concentration (as index to primary production)
List of Species	Indexes of Species Diversity
Density of Fish	Fish Production

Admittedly, system properties are more difficult to measure than standing state factors in that more time and greater technical skill may be required. However, the total assessment time and expense need not be greater because half a dozen or so well-chosen systems measurements are worth a whole host of miscellaneous component factor measurements. In practice, we find it effective to combine a few judiciously selected systems properties with a few "red flag" components, that is, factors or species which are of special concern in the local situation, as for example, an important game organism, an endangered species, a heavy metal or an organic poison that, by itself, threatens the health of the community and man.

A holistic approach to preparing EISs must involve ultimately an integration of economic and environmental values. There are many ways, as we shall see, to scale and weigh these seemingly uncomparable components so that they can be assessed together. Unfortunately, environmental and economic assessments usually are made by different teams or individuals who never communicate with one another (another example of the futility of the piecemeal approach). Environmental and economic assessors should be on the same team, or at least there should be a coordinated plan to integrate the results of the study of different groups of specialists. In the real world most important decisions are going to be made on the basis of some kind of economics. Considering environmental properties in monetary terms and vice-versa at least insures that benefit-cost will be based on a long-term analysis which includes secondary and tertiary impacts. Since we at the University of Georgia have for some time promoted the idea of merging ecology and economics, and since we have had some success in practice, a couple of case histories may be of interest.

Our first baptism under fire, so to speak, came prior to the enactment of the Federal NEPA Law. A large industrial company's request for permission to strip-mine phosphate ore which lies under the marshes and estuaries near Savannah had created a lot of controversy within state government and concern among the public, about possible adverse affects on the environment. The Governor of Georgia requested that the Chancellor of the University System of Georgia set up an ad hoc commission of faculty to study the situation so as to provide an objective basis for decision. The senior author served on this study commission which included marine biologists, geologists, engineers and resource specialists from both the University of Georgia and Georgia Tech. In addition to a detailed consideration of the possible biologic and economic impact of the mining on shrimp and sport fishing, we also had the University's Business Research Bureau make a study of the impact of phosphate mining on the general economy of Savannah and the coastal region of the state. This study clearly showed that the proposed mining would be a "carpetbagger operation" in that the out-of-state company proposed to haul off the ore to a fertilizer factor somewhere else where, of course, the major economic benefits would accrue. Thus, we could project that there would likely be only a small and temporary benefit to the local economy. Incredibly, some economists and many environmentalists as well seem unaware of the fact that there is

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little or no money in a natural resource at its source; money is made in processing or converting the resource to usable or consumable products. Unless one plans otherwise mining in particular will leave a local mess while money and its benefits go elsewhere. Again, one must consider the entire cycle of events, the holistic approach again!

On the basis of our report (see Cheatum, et al. 1968) the state turned down the lease request. Although this decision could have been based on any one of several impacts revealed by our study, including the probability of salt water intrusion into the freshwater aquafers that lie just under the ore vein, we believe that it was the combination of low economic appeal and high probability of environmental damage that clinched the matter. The publicity generated by the case resulted in a strong public demand for a Marshland Protection Law which was passed by the state several years later, thus insuring that any future proposals for major alteration of the estuarine zone will receive even greater attention and study than did the first test case. The best feature of the situation is that the resource is still there. If the world ever really needs the phosphate, we are confident it can be removed with far less environmental damage and with greater local economic benefit than would have been the case had the "quick and dirty" approach been allowed.

We were also encouraged by the experience to seek new ways to evaluate the economic worth of natural ecosystems. In collaboration with two Louisiana colleagues, a report on "The Value of the Tidal Marsh" was prepared in which energy provided the common denominator for converting the work of nature to monetary values, with emphasis on potential waste assimilation capacity. We have long ago lost track, but requests for the published bulletin on this (Gosselink, Odum and Pope 1974) are running into the thousands, which suggests that a lot of people are interested in the integration of economic and ecologic values.

Our next major experience with impact assessment came when the State Department of Transportation requested our help in routing an interstate highway north of Atlanta. The route originally chosen would cross a large lake, a state part, and cut into a sparsely inhabited forested area which conservationists felt should be preserved as a recreational green belt and as an air and watershed for Atlanta. As a result of the controversy, several alternate routes were surveyed, but the Department of Transportation (DOT) found itself unable to decide which route would be best for all concerned. Accepting the challenge, and on contract with the state, we set up a small study team of staff with diverse interests and backgrounds, including two postdoctoral systems ecology students. A linear vector analysis approach was adopted which allowed us to utilize the power of the computer for multifactor analysis, error estimation and validation. Data and/or expert opinions were available for more than 50 values which were grouped in four categories: economic and engineering considerations, environmental and land-use considerations, recreation considerations, and human and social considerations. We then numerically scaled the values so that the "apples and oranges" could be compared and summed. Next we weighted the values both as to the immediate impact and as to estimated impact 10 years later. A Delphi approach was used within the team to reach a consensus on weighting. To show the importance of including future or secondary impacts, let us consider the impact of a highway on a wilderness. The immediate effect of cutting a narrow path through the wilderness is quite small, but a major effect comes as commercial and other development takes place in an everwidening band along the route, assuming that there is little or no restriction on future land use, as would usually be the case with a public interstate highway.

A computer program was written so that the scale and weighted values could be summed to obtain a single impact index for each route. As in the case of any impact study, many components, even strictly economic or engineering ones, represent, at best, "expert" judgments or estimates and are thus subject to error. Accordingly, we introduced into the program an error factor based on the assumption that any one of the component values is subject to 50% error. As a matter of fact, we did not think many of the values were that far off, but we wanted to put in a generous estimate for human frailty! The scaled and weighted components were then summed to obtain a single impact index for each route. In Figure 1 the mean impact index, together with the 95% confidence interval, are displayed for the route originally proposed and the best available alternative route, that is, the route showing the lowest total impact on a relative scale. The best separation of routes was obtained in the totality run (all factors and their interactions considered), but the same general pattern of separation was obtained when either economic considerations or environmental considerations were left out. But

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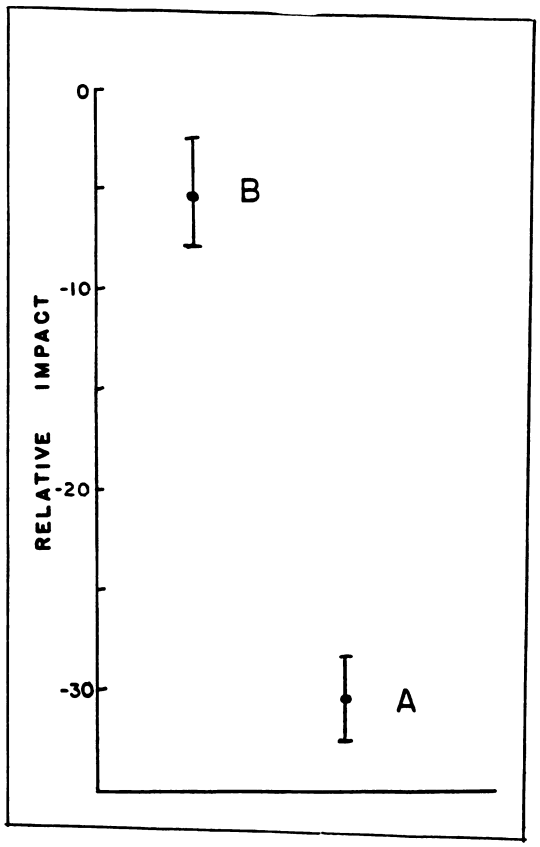

Figure 1. Mean impact index for the originally proposed route, A, and the best available alternative route, B, for Highway I-75 north of Atlanta.

leaving out future impact greatly reduced the separation, verifying the point already made that secondary impacts are often more important than primary impacts when it comes to deciding on options. Although the lowest impact alternate route was three miles longer than the original route, the estimated cost of these extra miles was less than the cost of the long bridge required for the other route. In this case the best route for the totality of man and environment was not more costly, a situation that was by no means evident at the beginning of the study. For more details on this test case, see Odum et al. (1976).

One advantage of the procedure just described is that it is thoroughly quantitative, yet sufficiently straightforward and uncomplicated so as to be understandable to the public as well as to professionals. With the aid of a few charts or slides we had no difficulty presenting the case at public hearings that were a part of the decision-making process. We were fortunate to be involved in the whole process down to the final decision when both state and federal DOT approved the alternate pathway. For example, the federal DOT engineers felt we had not given sufficient weight to certain factors and interactions so we were able to rerun the program with altered weighting until everyone was satisfied that the best alternative had been chosen. Too often the team that writes the EIS is completely isolated from the group that makes the decision, so that in essence the assessment is never validated, and neither group learns anything from the other. Under such a ridiculous and fragmented situation how can the art and science of technology assessment possibly advance?

PROFILE ANALYSIS

Returning to our graphic model theme, Figure 1, of course, represents one form of picture model from which both visual and statistical comparisons can be made at a glance. In this case all the properties or values are combined into a single index to show relative impact. Another approach would be to display separately component and ecosystem properties in the form of a profile. In Figure 2 the impact of an experimental eutrophication on an old-field community is shown. Properties and indices are arranged in two groups, those relating to community metabolism (left hand side of the diagram) and those relating to species structure (right side). In this case, adding macronutrients to the ecosystem elevated metabolic and biomass properties, but depressed diversity measures in comparison to the control profile. Since this pattern of response has been observed frequently in a variety of ecosystems, Figure 2 becomes a generalized model for the impact of eutrophication with mineral nutrients. In the absence of unexpected or unusual interactions one can confidently predict an increase in productivity and its related functions and a change in species structure in the general direction of reduced diversity. The initial state is important in determining whether such a predicted response will indeed occur. If, for example, the productivity is already very high, eutrophication could easily become a metabolic stress and reduce the rate. Likewise, if diversity is very low to begin with, nutrient enrichment can very well increase certain components of diversity, especially the evenness components. Thus, the baseline positions and the slopes of the profiles convey useful information at a glance.

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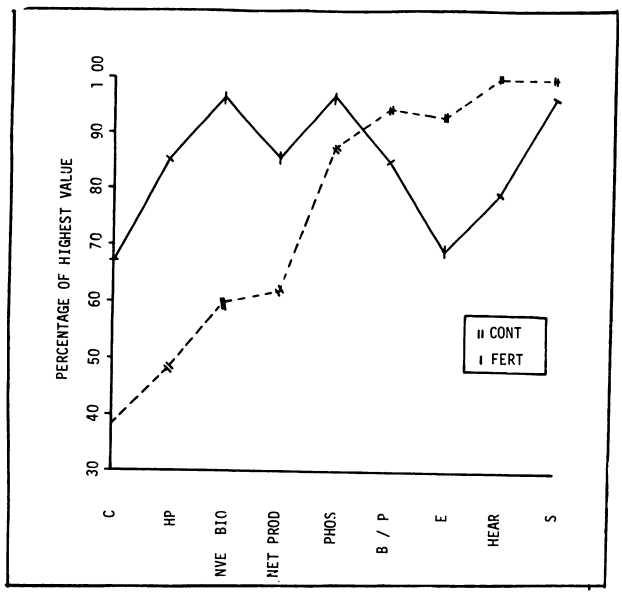

Figure 2. Ecosystem profile as graphic model of the impact of fertilization on the plant community and old-field community. Properties compared are: C = concentration of dominance; NP = net primary production; Ave Bio = Biomass; Phos = phosphate concentration in tissues; B/P = ratio biomass/NP; E = Evenness index of diversity; Hbar = Shannon index of diversity; S = species richness index of diversity (Bakalaar and Odum 1978).

Whether an impact, as shown in Figure 2, is considered to be desirable or undesirable depends not only on the assimilative stability of the system (i.e., ability to absorb a perturbation with minimum deflection of properties), but also on what is judged to be the most desirable future use of the environment by man. In the case of a body of water, for example, the impact of eutrophication may be undesirable if the water is to be used for drinking or swimming or trout fishing among other uses requiring very "clean" water. If, on the other hand, production of food or fiber is judged to be important, then an increase in productivity would be desirable, at least short of stressing some vital function such as oxygenation. Again, we see that future impacts and economic values must be included in the assessment if it is to result in a decision of lasting value. These considerations can also be displayed in profile fashion.

It is perhaps interesting to note that an ecological profile such as we have been discussing is analogous to a "biochemical profile" now widely used in medical practice as a quick and ready index to the general health of an individual.

Whenever practitioners meet to assess impact assessment, as it were, discussion and debate is almost sure to develop on the subject of the value of diversity indices. Since these indices are averaged or summed ratios often arbitrarily defined or based on assumptions not yet completely verified, it is widely recognized that a single index figure may obscure as much useful information as it reveals. One solution, of course, is to profile several different indices, each emphasizing a different component of diversity as was done in Figure 2. Another, and we think a better procedure, is to plot the relative importance of each kind of organism, as is shown in Figure 3, so as to display all of the information in the form of a profile. Importance values (numbers, biomass, or other indicators of importance) for each species or kind are plotted on a log scale in order of relative abundance and the evenly spaced points are then connected to form a curve. Robert Whittaker (1965) has called this type of profile a "dominance-diversity curve" since the first part of the curve depicts the relative position of the most important or dominant species and the long trailing part of the curve gives a picture of the number and relative standing of rare species. EIS practitioners would do well to review Whittaker's early paper since he also discusses theoretical significance of different profile shapes, possible mathematical models for basic shapes and what all of this may reveal about how organisms divide up niche space.

In Figure 3 are shown diversity profiles for the benthic fauna in three streams which provide a gradient from heavily polluted (with domestic wastes) to relatively pristine. It can be immediately seen that moderate pollution affects markedly the relative abundance of fairly common and rare species since it is the middle and terminal section of the curve that is most depressed below the level of the unpolluted profile. In the case of heavy pollution, all components are affected since the entire profile is markedly steepened. While diversity indices calculated from these data follow the pollution gradient (see Figure 3), the profiles exhibit additional information not evident in the index, namely the segment in the abundance sequence that is most affected.

So, if you are uncertain about diversity indices or not sure what they mean, why not

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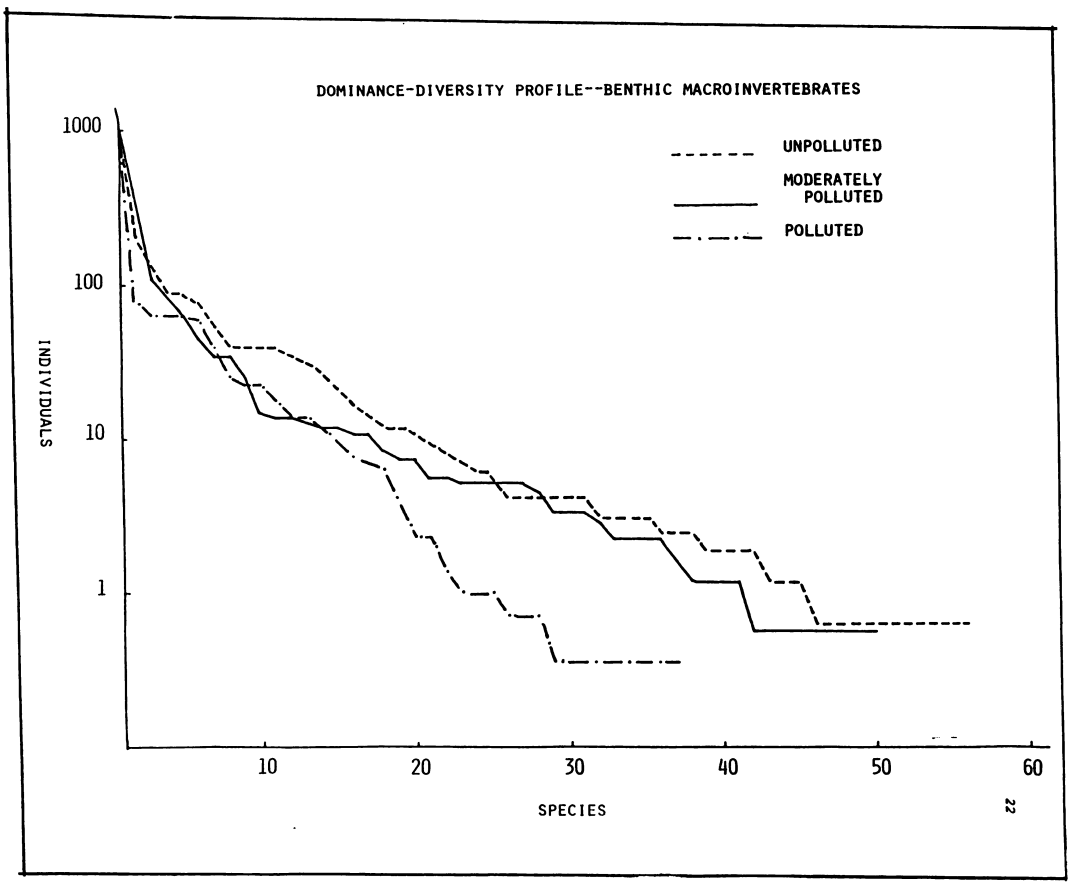

Figure 3. Dominance-diversity profiles for 3 parallel streams in the same watershed but which differ in the degree of pollution from urban domestic wastes. The Shannon diversity indexes for the streams are: unpolluted, 3.31; moderately polluted, 2.80; polluted, 2.45 (unpublished data of J.L. Cooley and Homer Sharp).

just get a piece of semi-log paper and plot your data as a profile, then let the eye and common sense be the judge. Remember that it is not necessary to identify or name all of the species; it's only important to be able to distinguish between kinds. Since larvae often occupy a niche that is different from the adult stage, it does not hurt, but probably helps if you classify larvae and adults as different "species" even if they are not. It is a lot better to classify everything that is distinctly different in basic appearance (body feature, color, etc.) as a different "kind" than it is to throw out all the immatures and other organisms that even the expert cannot identify as to species. Also, as already noted, one can convert profiles into mathematical formulas (curve fitting) and one can apply statistical methods to determine if profiles differ if it is necessary to go that far. Finally, diversity profiles of non-living components, as, for example, nutrient "species" or organic chemical "species," should also be instructive, although we must admit there has, as yet, been little effort to apply diversity concepts to the non-living portion of ecosystems.

But we have applied diversity concepts to the assessment of habitat diversity of large landscapes. Recently, we used a grid overlay on aerial photos to assess forest-type diversity on the Savannah River Plant reservation, an atomic energy experimental site which has recently been designated as a National Environmental Research Park. Despite the fact that the former agricultural lands in the area have now mostly been converted to pure pine plantations, the overall habitat diversity remains high because of the

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intermixture of a variety of natural vegetation types. As shown in Figure 4, the habitat diversity is very similar to the diversity of soil types which can be considered a good baseline index. However, if pine monoculture were to be extended to 50% or 75% of the land area, as has been suggested by U.S. Forest Service as a means of increasing wood pulp yield, then we can show that landscape diversity would be drastically reduced (Figure 4, points II and III). When we add to this undesirable effect the cost of conversion (expensive vegetation removal, drainage, channelization of streams, etc.) and the possibility of increased disease and insect control we can present a strong case against any further extension of pine monoculture.

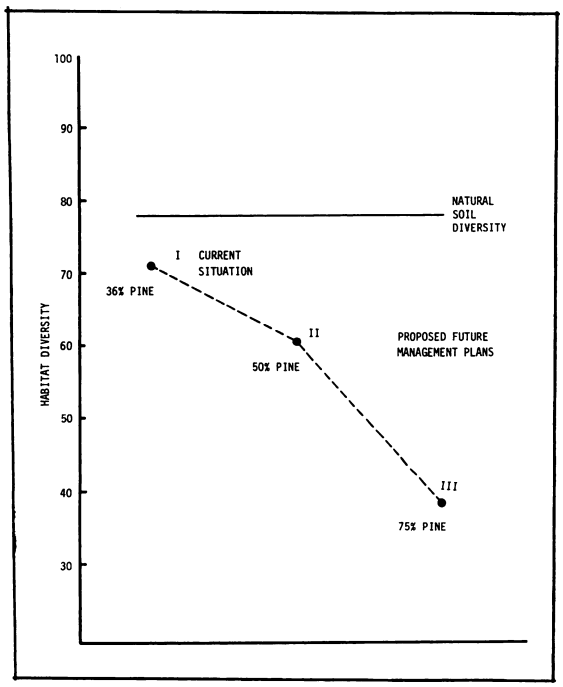

Figure 4. Habitat diversity of vegetation types and soil type of diversity (solid line) on the Dept. of Energy's Savannah River Plant Reservation under current (36% pine) and proposed future forest management plans that involve increasing use of pine monoculture. Diversity is plotted on scale where 100 equals maximum diversity possible for the number of forest or soil types present (Odum and Kroodsma 1977).

PERFORMANCE CURVES

Nearly everything man does has a gradient of impact possibilities on nature, ranging from enhancement or subsidy to severe stress, often depending on the intensity of the perturbation. The performance curve is a graphic form with possibilities for assessment of such a gradient. As shown in Figures 5 and 6, a performance curve is obtained when perturbation intensity is plotted along the horizontal axis and the response of one or more systems properties is plotted on vertical scales. Or, in more general terms, it is a plot of input against the output response of the ecosystem. A humped-backed or convex curve form would normally be expected. If a man-made input into the ecosystem involves a

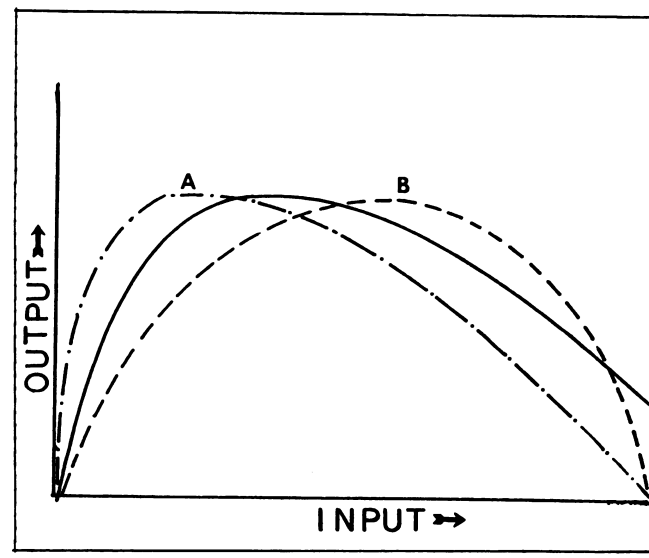

Figure 5. Generalized performance curves ranging from highly skewed-to-the-left to more symmetrical forms.

deadly poison, then the curve would be shifted to the left so that the optimum response is at zero discharge. However, in many cases man-made perturbations have the effect of enhancing at least certain functions when the input levels are low, only to become stresses when a certain plateau level is exceeded. Thermal discharges into a body of water that is naturally rather cool is an example. At low levels primary productivity, fish yields or waterfowl populations may be increased, but at high levels these desirable properties would

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be decreased. The problem in such cases is to determine which properties are enhanced or depressed and what levels are allowable or perhaps even desirable. Something like thermal pollution is not inherently good or bad. Reasonable decisions about its control can only be made when its "performance" in the subsidy-stress gradient is known, and the properties that are judged important to protect have been identified.

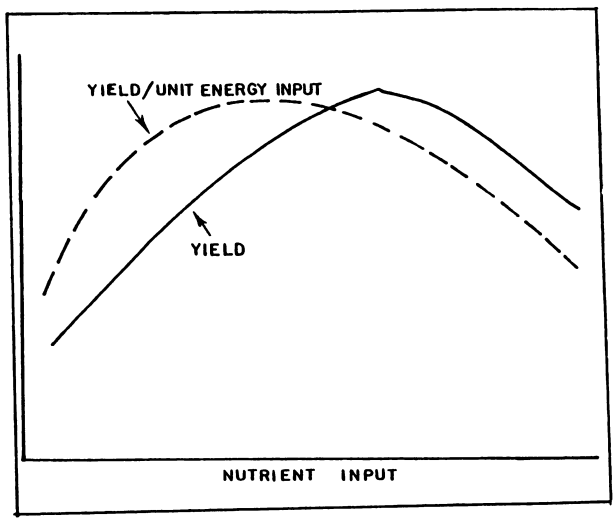

Figure 6. Hypothetical case where the plateau level of nutrient input comes at a lower level when yield is considered in terms of efficiency of energy use than when gross yield alone is the major consideration. There is some evidence that this situation applies to fertilizer-crop yield relationships.

A generalized performance curve takes the skewed-to-the-left form shown as curve A in Figure 5. The subsidy effect is marked, but restricted to a narrow zone and is soon followed by a broad plateau where the system is able to tolerate or assimilate the input without further change. The stress response takes the form of a long, gradual downhill slide as the intensity of the perturbation increases. This form is insidious because the favorable effects, as it were, are dramatic and easily detected, but there is no clean-cut, cut-off point where too much of a good thing can be judged to be undesirable. A common sense approach would be to stop at the very beginning or just before the plateau since it is probable that small, difficult to detect, stress, perhaps involving reproductive physiology or survival of young of key species, may begin in the plateau region (and produce a future undesirable effect) even though the overall function is stabilized. Assessment is much easier when the shape of the performance curve is more symmetrical, as shown in curve B in Figure 5.

We believe that specific curve forms may be linked with specific types of interactions between a particular class of ecosystems and a particular class of perturbations. If this proves to be true, then impact assessment can be made from a theoretical curve, perhaps generated by computer without the necessity of experimental testing. Or to be more cautious, such curves can provide a basis for experimental testing.

The hypothetical curves for Figure 6 illustrate what may be a general principle, namely, that the optimum level for efficiency of energy use comes at a lower, or at least at a different, level of input from that which produces maximum energy flow. For a crop, for example, the optimum yield per unit of energy input required is projected to come at a lower level of fertilization than does maximum net production. We need to find out if such a relation holds for the eutrophication of natural ecosystems. For additional discussion of performance profiles see Odum, Finn and Franz 1979.

Finally, we call your attention to H.T. Odum's energy language diagrams and flow charts as another form of graphic model which can be expanded into computerized systems analysis if needed and, therefore useful for impact assessment. In addition to recent books (H. T. Odum 1971 and H.T. and E. C. Odum 1976) which describe in detail this approach, he has written a short article that outlines specific ways that energy diagrams can be used for Environmental Impact Statements (H. T. Odum 1971).

SUMMARY

We have suggested that environmental impact assessment should evolve as rapidly as possible from the present largely descriptive component approach towards a more holistic approach which combines the use of broad ecosystem properties with specific local factors (i.e., "red flags") that are of public concern. The integration of economic and ecologic considerations was also stressed and two test cases were outlined to show how this combines the work of the impact assessor and the decision-maker was also emphasized. Several types of graphic models were presented and discussed as convenient devices for

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combining large amounts of information into easily understandable forms for comparative analyses and presentation.

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